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Simatic et al.

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[54] **METHOD OF ORDERING A PLURALITY OF MESSAGES FROM A PLURALITY OF SOURCES AND SYSTEM FOR IMPLEMENTING THE METHOD**

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[52] **U.S. Cl.** **395/182.02**; 395/200.68

[58] **Field of Search** 395/180–188, 395/200.01–200.83; 370/216, 217, 218, 219, 220, 221, 222, 223, 224, 225, 226, 227, 228; 379/220, 221; 455/7, 8, 13.1, 49.1, 103

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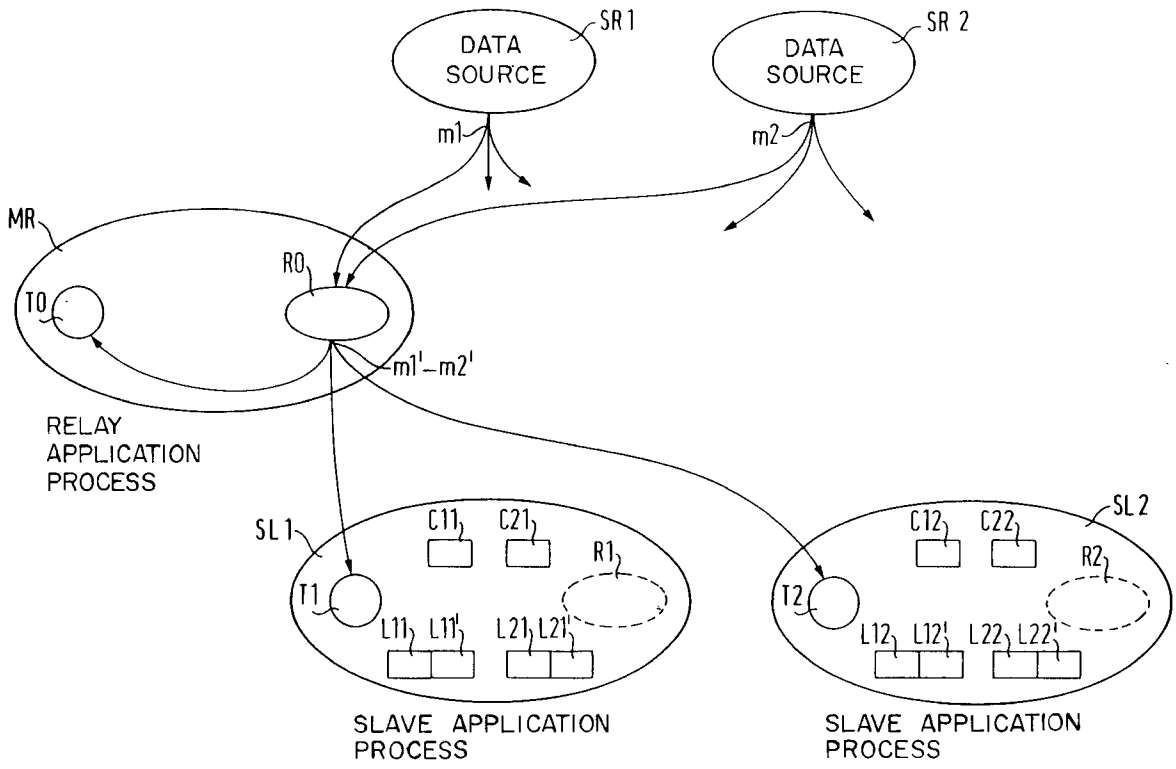
[57] **ABSTRACT**

A method is described for ordering a plurality of messages from a plurality of sources wherein, in order for all the application processes to receive the messages in the same order, a single relay process common to all the sources is selected from the application processes, the other application processes constituting slave processes. All messages broadcast by the sources are rebroadcast from the relay process to all the application processes, including the relay process. The relay process processes data from all messages that it rebroadcasts. The slave process processes only data from messages received via the relay process, data from messages received directly from the sources not being processed. Applications include data processing systems, in particular where part of the software is replicated.

12 Claims, 8 Drawing Sheets



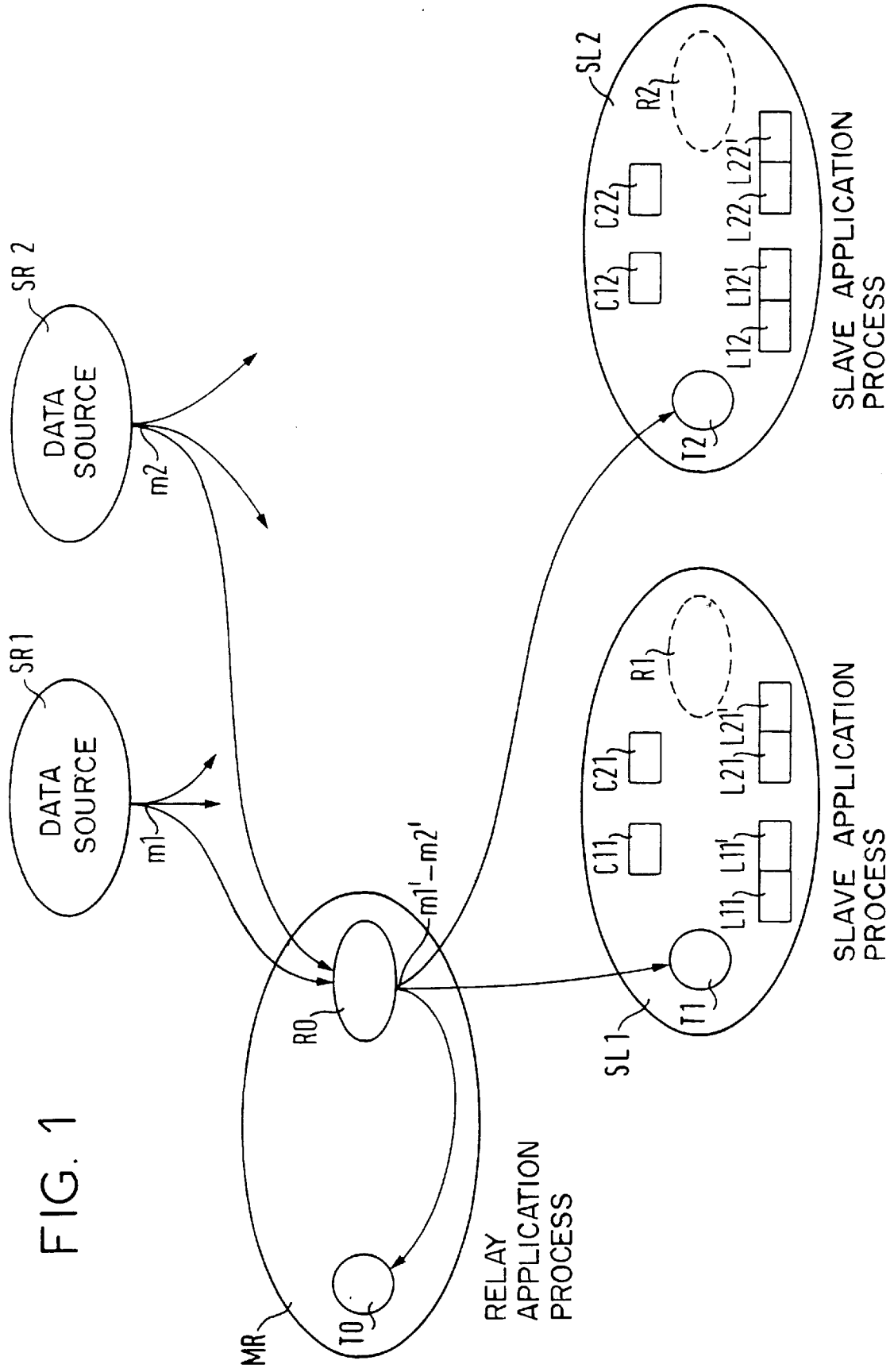

SR 2
DATA SOURCE
m2
SR1
DATA SOURCE
m1
m1'-m2'
R0
T0
MR
RELAY APPLICATION PROCESS
SL 2
R2
C22
C12
L22
L22'
L12
L12'
T2
SLAVE APPLICATION PROCESS
SL 1
R1
C21
C11
L21
L21'
L11
L11'
T1
SLAVE APPLICATION PROCESS

FIG. 1

FIG. 2

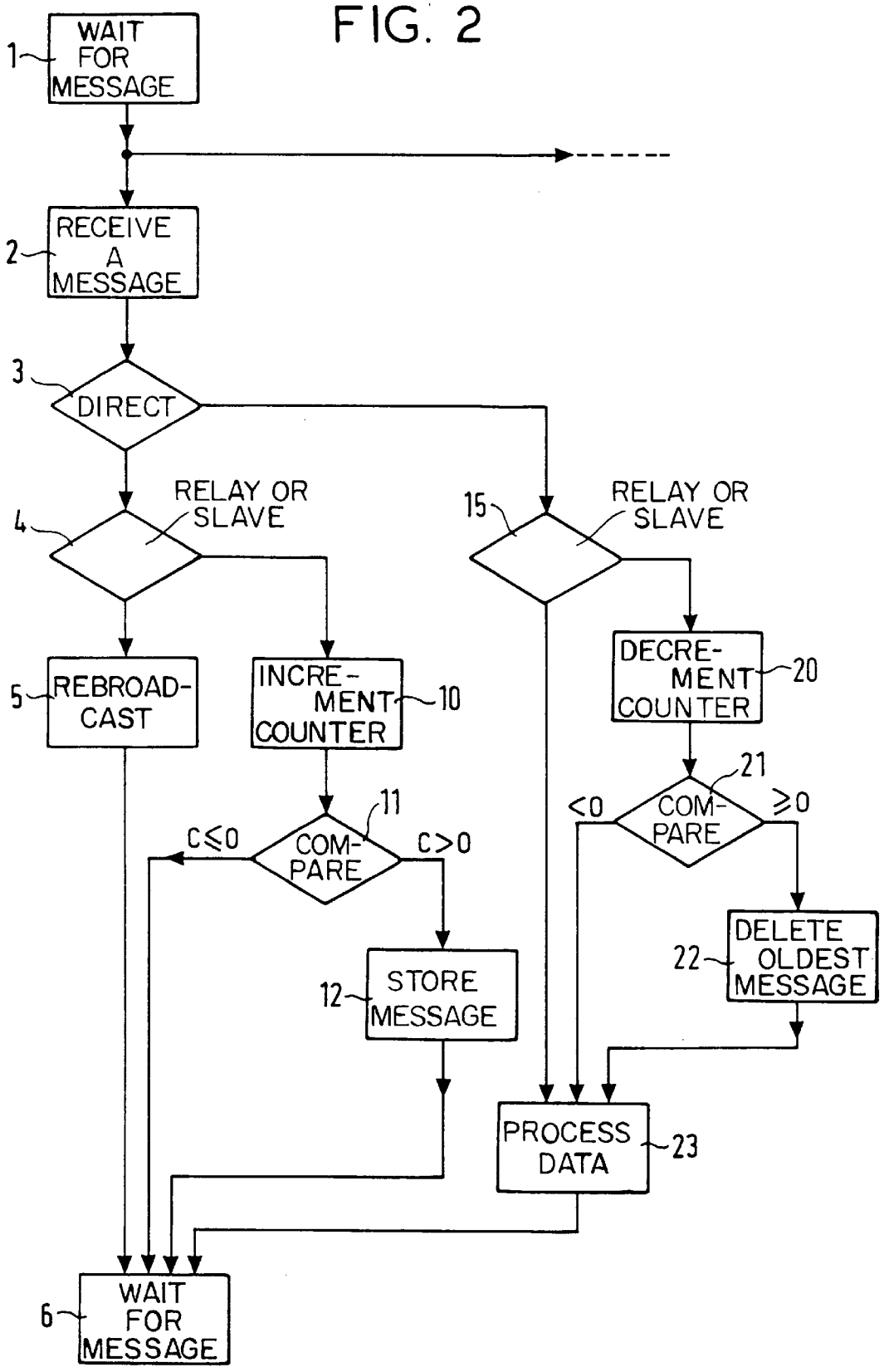
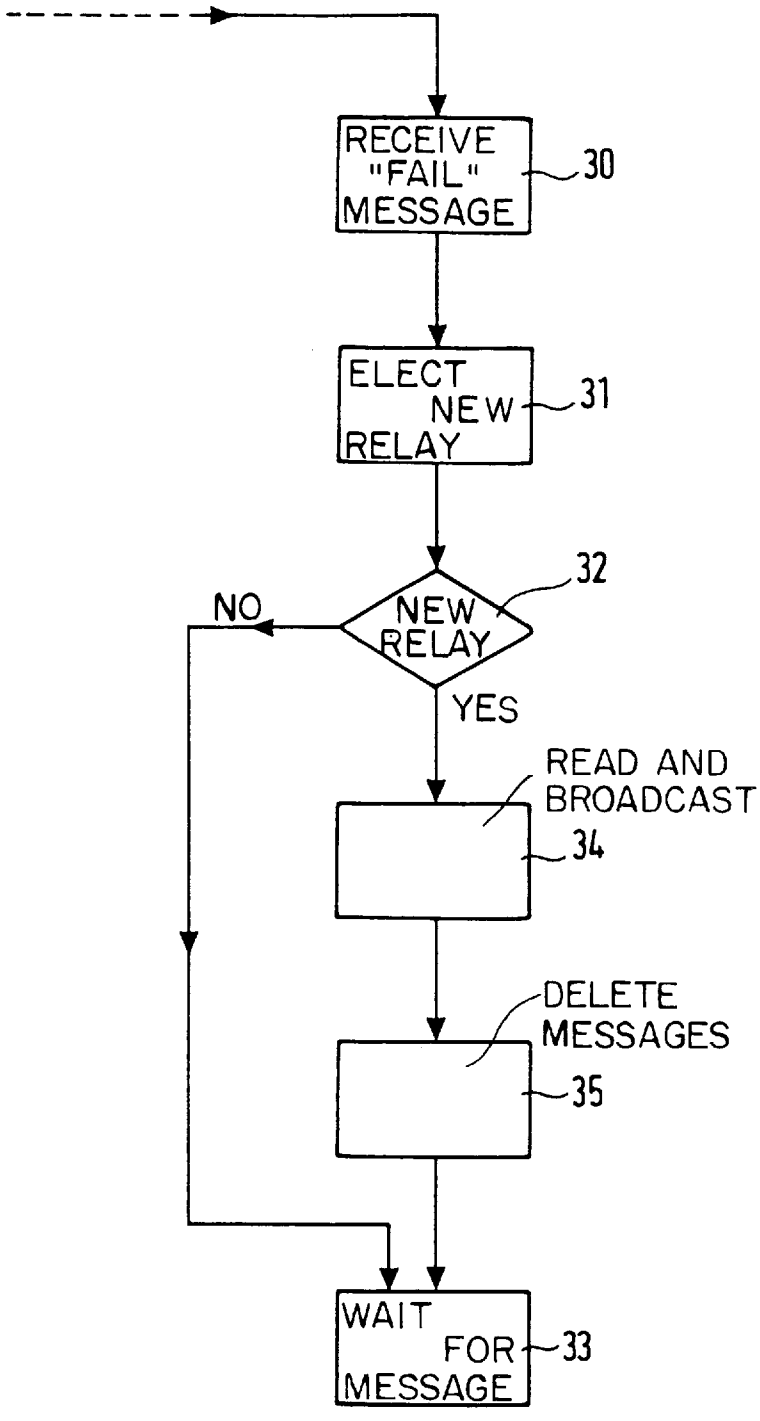

1
WAIT FOR MESSAGE
2
RECEIVE A MESSAGE
3
DIRECT
4
RELAY OR SLAVE
5
REBROAD-CAST
INCRE-MENT COUNTER
10
11
C≤0
COM-PARE
C>0
12
STORE MESSAGE
15
RELAY OR SLAVE
DECRE-MENT COUNTER
20
21
<0
COM-PARE
≥0
22
DELETE OLDEST MESSAGE
PROCESS DATA
23
6
WAIT FOR MESSAGE

FIG. 3


RECEIVE "FAIL" MESSAGE
30
ELECT NEW RELAY
31
NEW RELAY
32
NO
YES
READ AND BROADCAST
34
DELETE MESSAGES
35
WAIT FOR MESSAGE
33

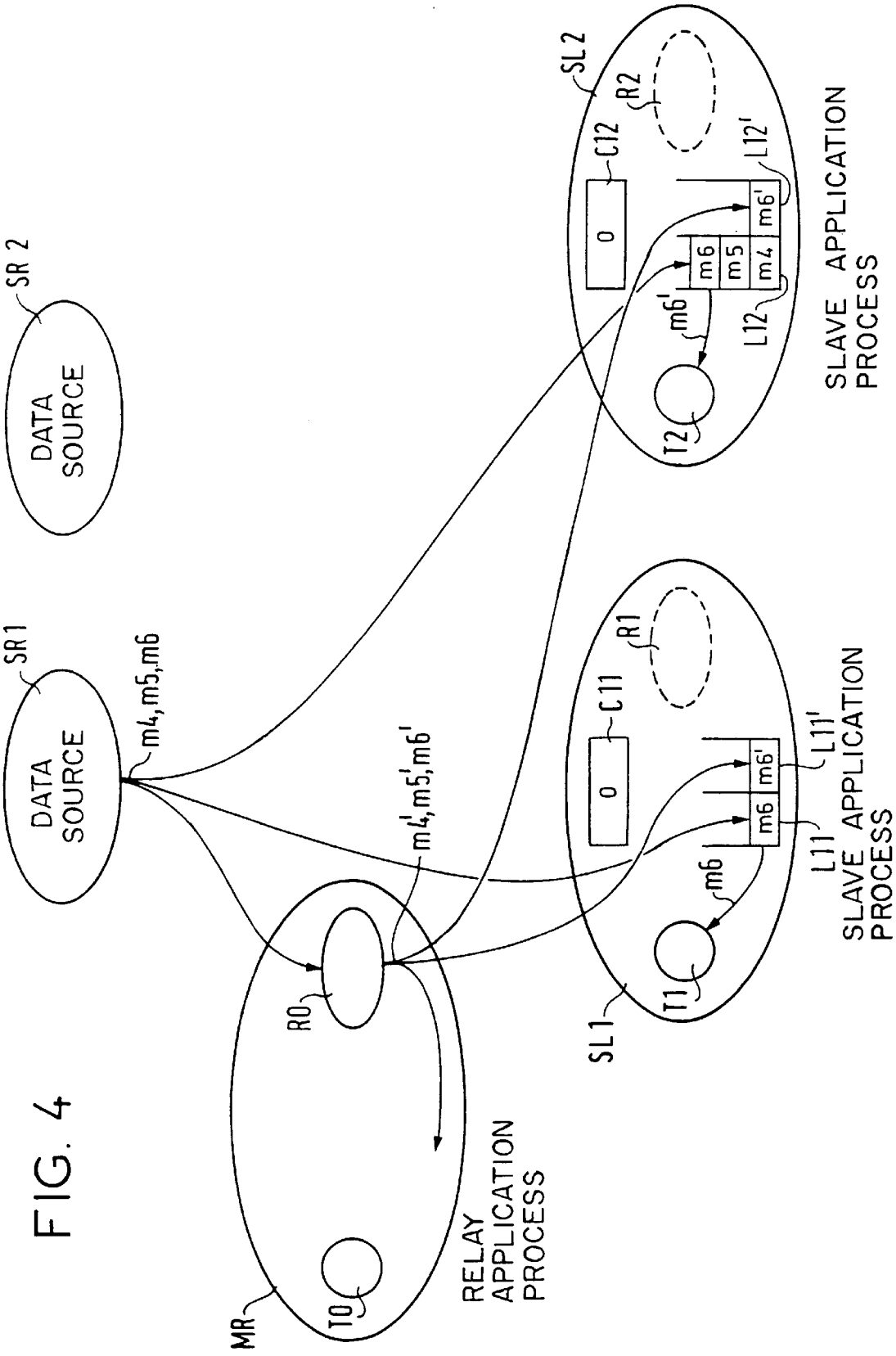

SR 2
DATA SOURCE
SR 1
DATA SOURCE
m4,m5,m6
m4',m5',m6'
MR
T0
R0
RELAY APPLICATION PROCESS
SL 2
R2
C12
0
L12'
m6
m5
m4
m6'
m6'
L12
T2
SLAVE APPLICATION PROCESS
SL 1
R1
C11
0
L11'
m6
m6'
m6
L11
T1
SLAVE APPLICATION PROCESS

FIG. 4

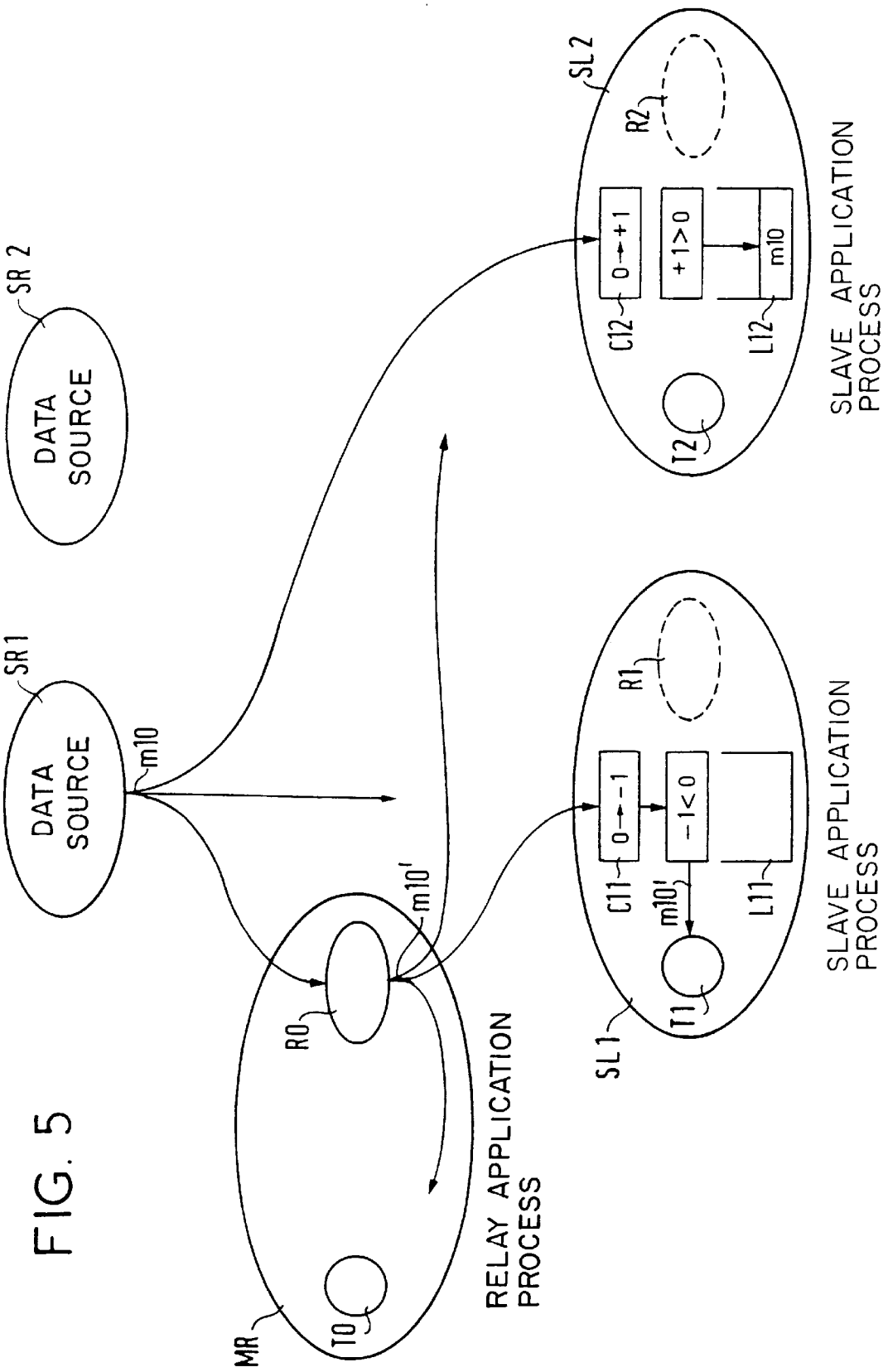

SR 2
DATA SOURCE
SR1
DATA SOURCE
m10
m10'
R0
T0
MR
RELAY APPLICATION PROCESS
SL 2
R2
0→+1
+1>0
m10
C12
L12
T2
SLAVE APPLICATION PROCESS
SL 1
R1
0→-1
-1<0
m10'
C11
L11
T1
SLAVE APPLICATION PROCESS

FIG. 5

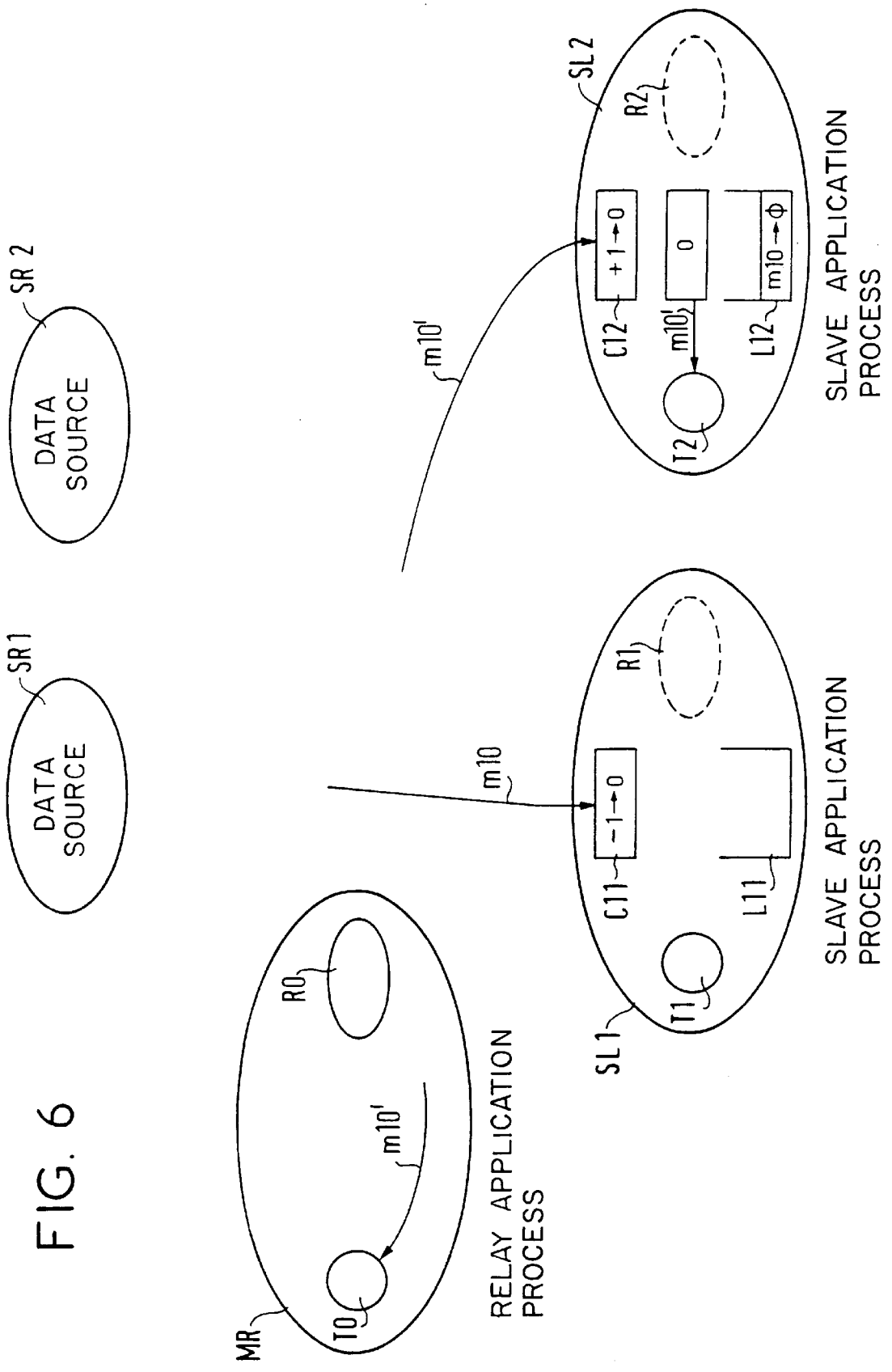

SR 2
DATA SOURCE
SR1
DATA SOURCE
m10'
SL 2
R2
C12
+1→0
0
m10'
L12
m10→φ
T2
SLAVE APPLICATION PROCESS
m10
R1
C11
-1→0
L11
T1
SL 1
SLAVE APPLICATION PROCESS
R0
m10'
T0
MR
RELAY APPLICATION PROCESS

FIG. 6

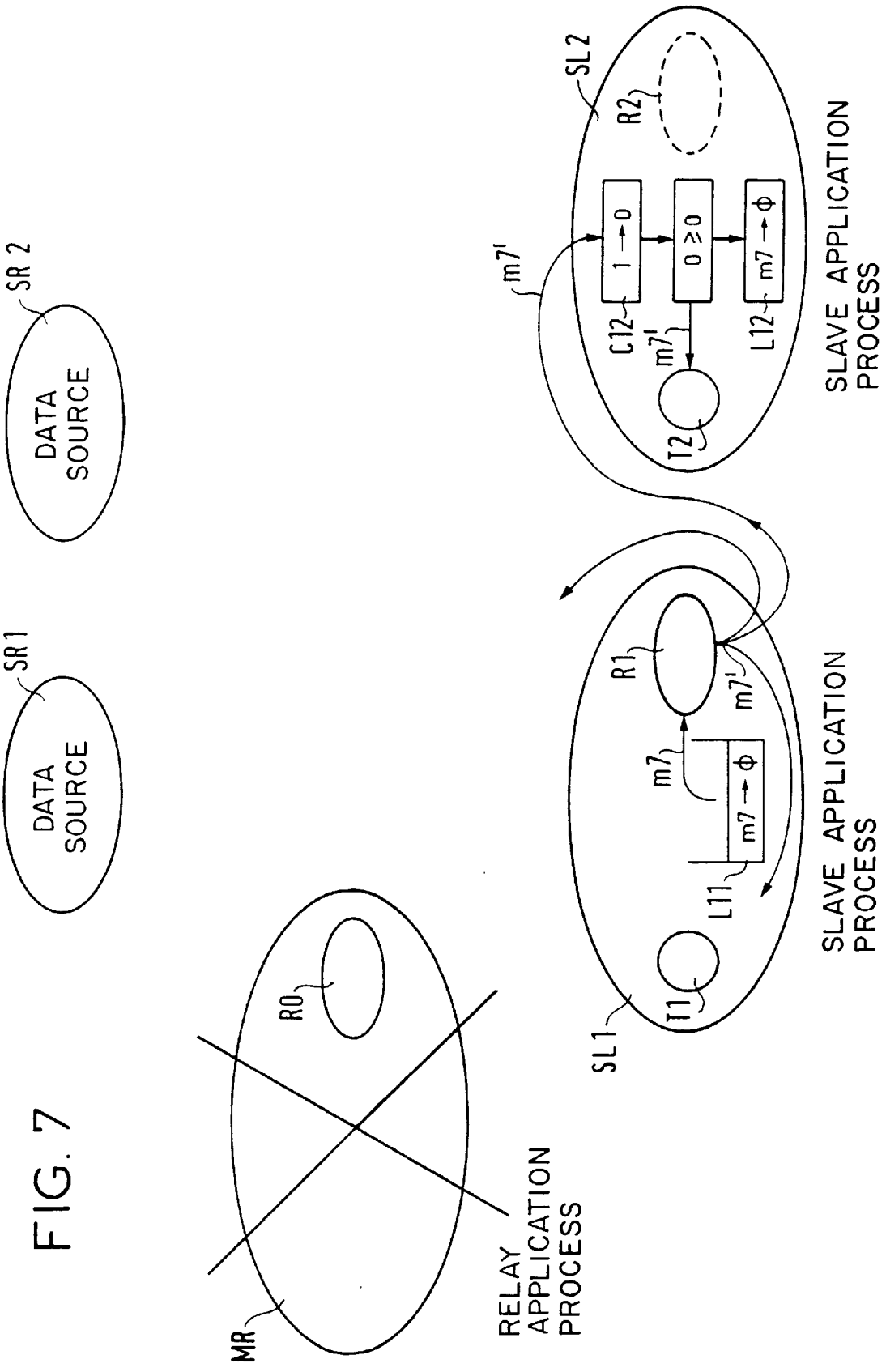

SR 2
DATA SOURCE
SR 1
DATA SOURCE
MR
RELAY APPLICATION PROCESS
R0
SL1
T1
L11
m7 → φ
m7
R1
m7'
SL2
T2
C12
1 → 0
m7'
0 ≥ 0
L12
m7 → φ
R2
m7'
SLAVE APPLICATION PROCESS
SLAVE APPLICATION PROCESS

FIG. 7

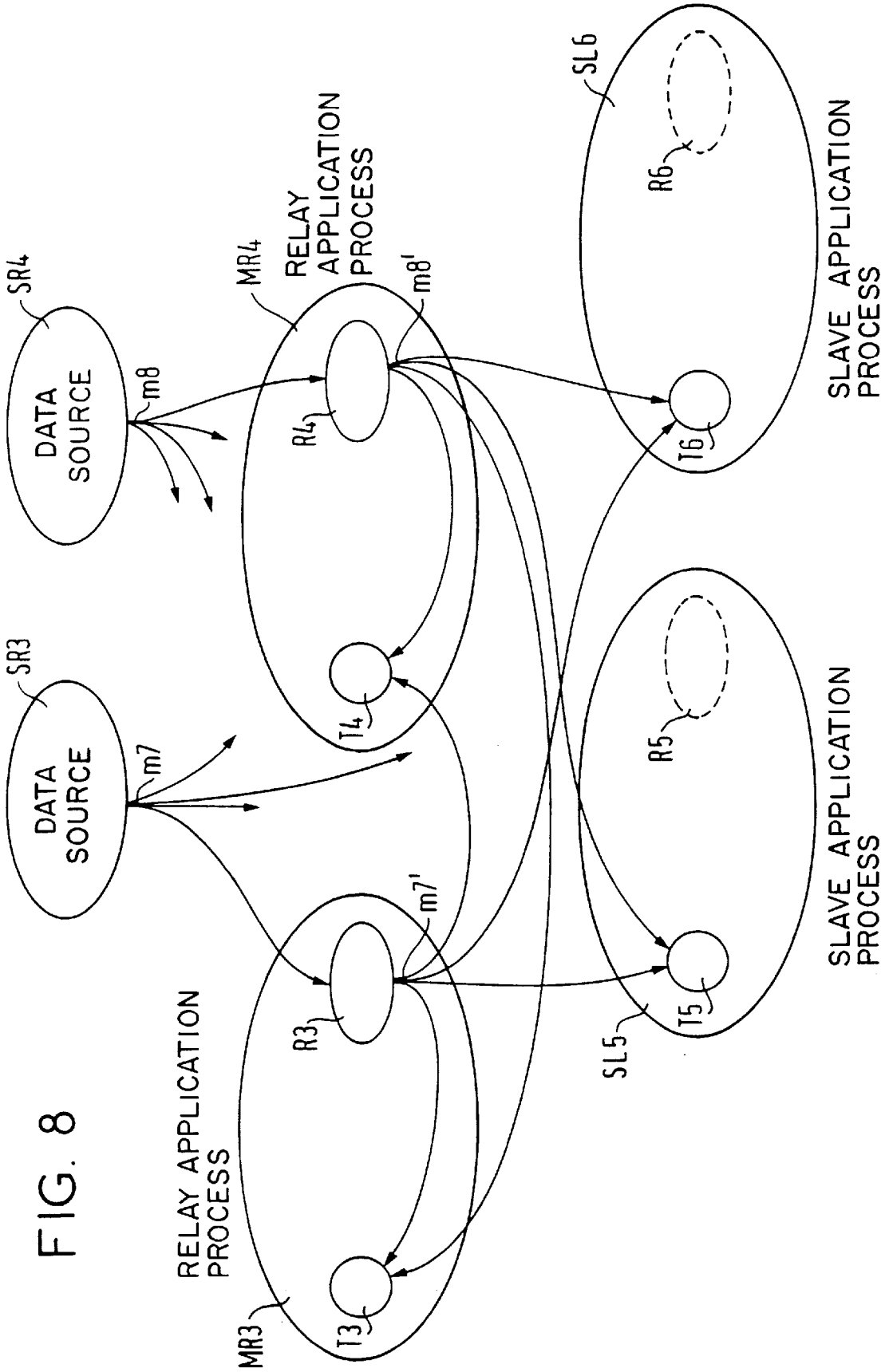

SR4
DATA SOURCE
m8
MR4
RELAY APPLICATION PROCESS
m8'
R4
T4
SL6
R6
T6
SLAVE APPLICATION PROCESS
SR3
DATA SOURCE
m7
m7'
R3
T3
MR3
RELAY APPLICATION PROCESS
R5
T5
SL5
SLAVE APPLICATION PROCESS

FIG. 8

METHOD OF ORDERING A PLURALITY OF MESSAGES FROM A PLURALITY OF SOURCES AND SYSTEM FOR IMPLEMENTING THE METHOD

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention concerns a method of and a system for ordering a plurality of messages from a plurality of sources addressed to a plurality of application processes so that all the application processes receive the messages in the same order. The invention applies in particular to a data processing system including a plurality of application processes that are replicas of one and the same application process, the replication being effected to enhance the reliability of the system, for example.

2. Description of the Prior Art

One way to guarantee the consistency of data in a system of this kind is to design the software of the system so that all the application processes behave as state machines, i.e. so that the behavior of an application process depends only on the data applied to an input of the process and on the order in which the data is applied to that input. Consequently, if the same data stream is applied to all the replicas of one and the same application process it is certain that the replicas will behave consistently. The data supplied to the various application processes of a system generally originates from a plurality of sources. Persons skilled in the art know how to implement a source of data broadcasting a series of messages to a plurality of application processes in a reliable and orderly manner. This broadcasting is reliable when it is certain that all of the addressee processes receive each broadcast message. It is orderly when it is certain that each addressee process receives the series of messages in the same order.

When a plurality of sources send respective series of messages to a plurality of application processes, there is no guarantee that the messages will be received in the same order by the various processes, even if each source taken individually sends the messages in a reliable and orderly manner. It is feasible to use the same reliable and orderly broadcast protocol for the various sources. This solution cannot always be applied, however, since in some cases there is no control over the broadcast protocol used by some data sources.

U.S. Pat. No. 5,363,503 describes a method of maintaining the consistency of data in a multiprocessor data processing system in which so-called primary application processes are duplicated at least once in the form of a back-up process to protect the system against the consequences of a processor failure. The processes carry out durable actions such as writing to a disk.

This method includes several steps.

One step is providing each processor with a message memory and a counter for counting the number of times the message memory is written.

The next is storing in memory data describing external events and their occurrence relative to internal events.

Another step, before any durable action of the processor supporting a primary process, is transmitting to the back-up process at least some of the messages in memory and the data describing external events and their occurrence relative to internal events.

In the event of failure of the processor supporting a primary process, the back-up process performs the processing of the messages and the data transmitted to it to ready the back-up process for replacing the primary process.

This method has the drawback of being complex to implement.

An aim of the invention is to propose a method that is easier to implement than the prior art method.

SUMMARY OF THE INVENTION

The invention consists in a method of ordering a plurality of messages from a plurality of sources addressed to a plurality of application processes able to process data from said messages, each source broadcasting a series of messages in a reliable and orderly manner and each receiving application process being capable of rebroadcasting a series of messages in a reliable and orderly manner to all said application processes, wherein, in order for all said receiving application processes to receive said messages in the same order, the method involves:

- selecting from the application processes a single relay process common to all the sources, the other application processes constituting slave processes;
- rebroadcasting all messages broadcast by the sources from the relay process to all the application processes, including the relay process;
- processing in the relay process data from all messages that it rebroadcasts; and
- processing in the slave processes only data from messages received via the relay process, data from messages received directly from the sources not being processed.

The invention also consists in a variant of the above method consisting in choosing a plurality of relay processes, a relay process being chosen for a plurality of sources, but each source having only one relay process, and all the relay processes applying the same reliable and orderly broadcast protocol.

The above method assures reliable and orderly broadcasting since a channel passes through the relay process(es) that serialize(s) messages from the various sources in a particular order and rebroadcasts them reliably.

In a preferred embodiment, in order to remedy failure of the current relay process, the method in each slave process receiving a message includes:

- storing the message if a the slave process has not received it already via the relay process;
- then deleting it if the slave process subsequently receives it via the relay process; and
- rebroadcasting, then deleting, all messages stored and not yet deleted if the current relay process has failed and if the slave process concerned becomes the new relay process common to all sources.

In a preferred embodiment, in order to determine, in a slave process, if the slave process has already received a message broadcast by a source via the relay process before it receives it directly from a source, the method includes:

- decrementing a counter specific to the slave process and the source each time that the slave process receives a message from the source via the relay process;
- incrementing the counter each time the slave process receives a message from a source directly; and
- concluding that the slave process has not already received a message broadcast by a source via the relay process if and only if the algebraic value of the counter is positive.

This embodiment is particularly simple since it enables monitoring of the correct operation of a relay process by a single counter in each slave process.

The invention also consists in a system for implementing the above method.

The invention will be better understood and other details of the invention will emerge from the following description and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram showing one example of a data processing system and illustrating a first embodiment of the method of the invention.

FIGS. **2** and **3** constitute a flowchart of the operations of this first embodiment.

FIG. **4** shows an initialization step of this first embodiment.

FIGS. **5** and **6** illustrate the situation in which application processes receive a message directly from a source before receiving the same message rebroadcast by a relay process.

FIG. **7** illustrates the situation in which the current relay process has failed and has been replaced by a new relay process.

FIG. **8** is a diagram showing a different data processing system and illustrating a second embodiment in which there are a plurality of relay processes respectively corresponding to a plurality of sources.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The data processing system shown in diagrammatic form in FIG. **1** includes two sources of data SR**1**, SR**2** and three application processes MR, SL**1**, SL**2** to which the data is addressed. The data sources SR**1** and SR**2** can be application processes. Neither of them receives data sent by the other. Each of the sources SR**1**, SR**2** sends a stream of messages to all of the application processes MR, SL**1**, SL**2**. Each source broadcasts its stream of messages in a reliable and orderly manner, but it is not possible (at least in this example) to coordinate the sending of two streams of messages so that on reception in each of the application processes MR, SL**1**, SL**2** the two streams of messages interleave in the same order.

The application processes MR, SL**1**, SL**2** include respective processing parts T**0**, T**1**, T**2** for processing data from the respective messages received by these application processes.

Each application process MR, SL**1**, SL**2** includes a respective part R**0**, R**1**, R**2** capable of rebroadcasting a series of messages in a reliable and orderly manner to all the application processes, including the processing part of the same application process.

In the first embodiment of the method of the invention, the aim is to choose from the application processes MR, SL**1**, SL**2** a process constituting a relay process, of which there is only one and which is common to all the sources SL**1**, SL**2**. In this example the process MR is chosen as the relay process. The other application processes SL**1** and SL**2** constitute slave processes. The function of the relay process MR is to receive all the messages broadcast by all the sources SR**1**, SR**2** and to rebroadcast them in a reliable and orderly manner to all the application processes, including itself (its processing part T**0**).

In the relay process MR the part R**0** is activated to rebroadcast in a reliable and orderly manner all messages that the relay process MR receives. The rebroadcast messages are identifiable as such. In the slave processes SL**1** and SL**2** the parts R**1** and R**2** are inactive, but can be activated subsequently in the event of failure of the current relay process MR (see below).

A first feature of the method of the invention is that the slave processes SL**1**, SL**2** refuse to process data from messages received directly from the sources SR**1**, SR**2**. In this example, the sources SR**1** and SR**2** respectively send a message m**1** and a message m**2** which are received in any order by the application process MR. They are received by the application process SL**1** in any order that is independent of the previous order and by the application process SL**2** in any order that is independent of the previous orders.

The relay process MR receives the messages m**1** and m**2** sent by the sources SR**1** and SR**2** in the order m**1**–m**2**, for example. The part R**0** retransmits these messages in the form of messages m**1**'–m**2**' in a reliable and orderly manner to the processing part T**0** of the relay process MR and to the slave processes SL**1** and SL**2**, for immediate processing of the data contained in these messages by the processing parts T**0**, T**1**, T**2**, respectively. The fact that the two messages m**1** and m**2** are rebroadcast by the same relay process MR ensures that all the processing parts T**0**, T**1**, T**2** receive the replicas m**1**'–m**2**' of the messages m**1**–m**2** in the same order.

Additional features of the method of the invention remedy failure of the application process used as the relay. In this example, these additional features employ two counters C**11**, C**21** and four log registers L**11**, L**21**, L**11**', L**21**' in the slave process SL**1** and two counters C**12**, C**22** and four log registers L**12**, L**22**, L**12**', L**22**' in the slave process SL**2**. The counters C**11**, C**12** and the log registers L**11**, L**11**', L**12**, L**12**' are specific to the source SR**1**. The counters C**21**, C**22** and the log registers L**21**, L**21**', L**22**, L**22**' are specific to the source SR**2**. Their operation is described later. The log registers L**11**', L**12**', L**21**', L**22**' are used only during an initialization phase and store only messages received via the relay process MR. The log registers L**11** and L**12** are used to store messages sent by the source SR**1** and received directly. The log registers L**21** and L**22** are used to store messages sent by the source SR**2** and received directly. All these log registers are memories of the first-in/first-out type.

FIG. **2** shows a first part of the flowchart of the operations carried out in the first embodiment. This first part concerns normal operation of the single relay process that is common to all the sources. FIG. **3** shows another part, including the operations carried out if the slave application process receives a message indicating that the current relay process has failed. FIGS. **5** through **7** then illustrate these operations by means of examples.

In FIG. **2**, operation **1** consists in waiting for a message. Operation **2** consists in a receiving a message other than a "relay failed" message. Operation **3** consists in determining the origin of the message received:

- If operation **3** concludes that the message has come directly from the source SR**1**, SR**2**, operation **4** consists in determining if the application process that received the message is the relay process or a slave process:
  - If this application process is the relay process MR, operation **5** consists in rebroadcasting the received message in a reliable and orderly manner to all of the application processes, including the processing part of the process concerned. Operation **6** then consists in waiting for another message.
  - If the process concerned is not the relay process MR, operation **10** consists in incrementing a counter in the process concerned and corresponding to the source that sent the message concerned. For example, this is the counter C**11** if the process concerned is the slave process SL**1** and if the source that sent the message concerned is the source SR**1**.

Operation **11** then consists in comparing the algebraic value of this counter to zero:

If the algebraic value is negative or zero, the next operation is operation **6** which consists in waiting for another message, since this algebraic value represents the fact that the broadcasting by the relay process was in advance of the direct broadcasting of messages from the source SR**1** to the slave process SL**1**, for example.

If the algebraic value of the counter is positive, operation **12** then consists in storing the message in a log register in the slave process concerned and corresponding to the source that sent the message concerned. For example, this is the log register L**11** in the slave process SL**1** for a message sent by the source SR**1**. Operation **6** then consists in waiting for another message. The positive algebraic value corresponds to a delay in the rebroadcasting by the relay process MR of messages sent by the source SR**1** in this example. This time-delay could be due to the failure of the relay process MR. This is why operation **12** consists in backing up the message in a log register L**11**. The slave process is not entitled to process data from this message since it was received directly from the source SR**1**.

If operation **3** concludes that the message received is a message rebroadcast by the relay process MR, operation **15** then consists in determining if the process that received the message is the relay process or a slave process:

If the process concerned is the relay process MR, operation **23** consists in processing the data contained in the message in the processing part T(n) of this process. Operation **6** then consists in waiting for another message.

If the process concerned is a slave process SL**1** or SL**2**, operation **20** consists in decrementing a counter in the process concerned and corresponding to the source that sent the message concerned: for example, this is the counter C**11** in the slave process SL**1** if the message was sent by the source SR**1**, for example. Operation **21** then consists in comparing the algebraic value of this counter to zero:

If the algebraic value is negative, operation **23** consists in processing the data contained in the received message. However, this message is not stored in the log register corresponding to the source SR**1** since the negative value of the counter indicates that broadcasting by the relay is in advance of direct broadcasting of the messages by the source SR**1**. There is therefore no particular problem.

If the algebraic value of the counter is positive or zero, operation **22** consists in deleting the oldest message stored in the log register corresponding to the source that sent the received message, because the reception of this message via the relay process cancels out all or part of the time-delay of broadcasting by the relay relative to the direct broadcast. Operation **23** then consists in processing the data from the received message in the processing part of the process that received the message. Finally, operation **6** consists in waiting for another message.

If one of the slave processes SL**1**, SL**2** detects failure of the current relay process MR, the reliable and orderly broadcast protocol, which links all the processes, broadcasts a "relay failed" message to all the application processes. The slave processes all implement a protocol for electing a new relay process, for example on the basis of a criterion of optimal distribution of the workload of the various slave processes. The slave process that is elected as the new relay process activates its part capable of rebroadcasting a series of messages in a reliable and orderly manner. This is the part R**1**, R**2** in the slave processes SL**1**, SL**2** respectively.

FIG. **3** shows the second part of the flowchart of the operation of the first embodiment of the method in accordance with the invention, this part more particularly concerning the operations carried out by an application process when it receives a "relay failed" message.

A first operation **30** consists in receiving this "relay failed" message. Then operation **31** consists in participating in the election of the new relay process. A test **32** determines if the process concerned is the new relay process, common to all the sources:

If the process concerned is not the new relay process, operation **33** simply consists in waiting for a new message.

If it is the new relay process, operation **34** consists in reading each log register of the process and broadcasting all the messages contained in it. Operation **35** then consists in deleting the messages that each log of that process contains. Operation **33** then simply consists in waiting for a new message.

FIG. **4** shows the same system as FIG. **1** and illustrates an initialization step of the first embodiment in the method in accordance with the invention. By way of example, FIG. **4** shows:

a first log register L**11** and a second log register L**11**' in the slave process SL**1** and corresponding to the source SR**1**;

a first log register L**12** and a second register L**12**' in the slave process SL**2** and corresponding to the source SR**1**. There is a pair of similar log registers L**21** and L**22** corresponding to the source SR**2** in the slave process SL**1**, but it has not been shown in FIG. **4** to make the latter clear. Likewise, there is another pair of log registers L**22** and L**22**' corresponding to the source SR**2** in the slave process SL**2** but it is not shown in FIG. **4**.

When a slave process SLj (where j=1, 2, . . .) receives a message from the source SRi (where i=1, 2, . . .) via the relay process MR it compares the contents of the two log registers Lij and Lij' corresponding to the source SRi. If it detects that it has received the same message directly (the message is in Lij) and via the relay process MR (the same message is in Lij') the initialization phase terminates. It loads the counter Cij with a value corresponding to the time-delay or the advance that it finds:

It loads a zero value into the counter if it finds that there is no time-delay of broadcasting by the relay process MR relative to direct broadcasting by the source SR**1** (the message it has just received via the relay process corresponds to the last message received directly from the source). It then processes the last message received and deletes the content of the log registers Lij and Lij', if any.

It loads a value +n into the counter if it finds that there is a time-delay of n messages for broadcasting by the relay process MR relative to direct broadcasting by the source SR**1** (the message that it has just received via the relay process is followed by n messages in the log

register storing messages received directly from the source). It then processes the last message received and deletes the content of the log registers Lij and Lij', if any, with the exception of messages stored in Lij not yet received via the relay process MR.

FIG. **4** illustrates the initialization phase by means of an example in which the source SR**1** sends a series of messages m**4**, m**5**, m**6** to all the application processes MR, SL**1**, SL**2**. The messages are received by the relay process MR in the order m**4**–m**5**–m**6** and are rebroadcast by the part R**0** in a reliable and orderly manner in the form of a series of messages m**4**'–m**5**'–m**6**' which are therefore received in that order by the processing part T**0** of the relay process MR and by the slave processes SL**1**, SL**2**.

The slave process SL**1** starts up under conditions such that it receives only the messages m**6** and m**6**'. It stores m**6** in the first log register L**11** and m**6**' in the second log register L**11**'. It compares the contents of the two log registers L**11** and L**11**' corresponding to the source SR**1** and detects that it has received the same message directly and via the relay process MR. As m**6**' corresponds to the last message from Lij, it loads the counter C**11** with the value 0. It transmits the message m**6**' to the processing part T**1**. It then deletes the contents of the log registers L**11** and L**11**'.

The slave process SL**2** starts up under conditions such that it receives the messages m**5** and m**6** directly from the source SR**1**. It stores them in the first log register L**12**. It also receives the message m**5**' broadcast by the relay process MR. On the other hand, it never receives the message m**4**' that preceded the message m**5**'. It stores m**5**' in the second log register L**12**'. It compares the contents of the two log registers L**12** and L**12**' and concludes that the broadcast via the relay process MR is subject to a time-delay corresponding to one message, i.e. the message m**6**. It therefore loads the counter C**12** corresponding to the source SR**1** with the value +1. It transmits the message m**5** to the process part T**2**. It then deletes all the messages from the log register L**12** except for the message m**6** and deletes the contents of the log register L**12**'.

When the initialization phase has terminated, it is possible to detect and to remedy any broadcast time-delay due to failure of the relay process. Consequently, the order and the consistency of the messages are protected against failure of the relay process.

FIG. **5** shows the operation of the same system immediately after the initialization phase. In the situation represented a message m**10** reaches the slave process SL**2** faster via the relay process MR (as message m**10**')than the direct broadcast (as message m**10** per se). On the other hand, the replica m**10**' broadcast by the part R**0** of the relay process MR reaches the slave process SL**1** faster When the original message m**10**.

When the slave process SL**1** receives the message m**10**', it decrements the counter C**11** by one unit. At the time in question it contains a value 0. The counter C**11** thereafter contains a value −1, a negative value indicating that broadcasting via the relay process is in advance by one message, from the point of view of the process SL**1**. The message m**10**' that has passed through the relay process is transmitted to the processing part T**1** for the latter to process the data that the message contains. The first log register L**11** remains empty.

Reception of the message m**10** by the slave process SL**2** causes the counter C**12**, which previously contained the value 0, to be incremented by one unit. The counter C**12** then contains a value +1, a positive value indicating that broadcasting by the relay process MR has a certain time-delay relative to direct broadcasting from the source SR**1**, from the point of view of the process SL**2**. The message m**10** is then written in the log register L**12** that was empty.

FIG. **6** shows what happens after this, when the message m**10**' replicating the message m**10** is received by the slave process SL**2** and when the message m**10** is received by the process SL**1**. In the slave process SL**1**, reception of the message m**10** causes the counter C**11** to be incremented by one unit. Its content goes to 0, which registers the fact that broadcasting via the relay process MR has a zero time-delay relative to direct broadcasting from the source SR**1**, from the point of view of the process SL**1**. The log register L**11** remains empty.

When the slave process SL**2** receives the message m**10**' it decrements the value of the counter C**12**. This value changes from +1 to 0. The fact that this value is zero means that rebroadcasting by the relay process MR is not subject to any time-delay relative to direct broadcasting. The message m**10**' is transmitted to the processing part T**2** for the latter to process the data of the message and the message m**10** is deleted from the log register L**12**.

FIG. **7** shows failure of the relay process MR. A "relay failed" message has been sent by the reliable and orderly broadcast protocol that links all the application process. The slave processes SL**1** and SL**2** have elected a new relay process. At the time in question, the election is finished and all of the application processes have been advised that SL**1** is the new relay process. The application process SL**2** remains a slave process. In the new relay process SL**1**, the part R**1** capable of rebroadcasting a series of messages in a reliable and orderly manner is activated to enable the relay function. Its counters, including counter C**11**, are de-activated.

In the example shown in FIG. **7**, the log register L**11** in the slave process SL**1** and corresponding to the source SR**1** contains a single message m**7** received direct from the source SR**2** and never rebroadcast via the relay process MR, because the latter has failed. When it is advised that it has been elected as the relay process, the process SL**1** reads the content of all its log registers. It finds the message m**7** in the register L**11**. The part R**1** of the new relay process SL**1** rebroadcasts the message m**7** in the form of a message m**7**' to all the application processes. In this way the new relay process SL**1** completes the broadcasting of the message m**7** that the failed relay process MR had not been able to perform.

The slave process SL**2** had also stored the message m**7** in its log register L**12** and the corresponding counter C**12** contains the value +1. When it receives the message m**7**' the process SL**2** decrements the counter **12** by one unit. The value of the counter C**12** goes to 0, which means that rebroadcasting by the relay process is not subject to any time-delay relative to direct broadcasting. The message m**7**' is transmitted to the processing part T**2** and the like message m**7** is deleted from the log register L**12**.

In the first embodiment of the method of the invention, described previously, there is only one relay process MR common to all the data sources SR**1**, SR**2**. The fact that there is only one relay process guarantees that the series of messages received by the various slave processes SL**1**, SL**2** are identical since they are broadcast by the part R**0** of the only process that is used as a relay. In the second embodiment of the method of the invention a plurality of application processes are used as relays. In particular, there may be a respective different relay process for each source. On the other hand, it is not possible for more than one process to be the relay for the same source at the same time. It is also

feasible for a relay process to be common to some of the sources but not all of them.

It is then essential for the processes used as relays to apply the same protocol for broadcasting messages in a reliable and orderly manner so that the rebroadcasting of the messages by all of the relay processes is coordinated so that the series of messages retransmitted is in a particular order. European patent application No. 0 650 280 describes a reliable and orderly broadcast protocol of this kind that can be applied simultaneously by a plurality of application processes.

FIG. **8** shows this second embodiment of the method of the invention in the example of a system including two relay processes MR**3** and MR**4** respectively rebroadcasting messages transmitted by two sources SR**3**, SR**4**. Note that they are also slave processes for the sources SR**4** and SR**3**, respectively. The relay processes MR**3** and MR**4** include respective processing parts T**3** and T**4** and two parts R**3** and R**4** capable of rebroadcasting a series of messages in a reliable and orderly manner using the same protocol. This example further includes two processes SL**5** and SL**6** that are slaves for the two sources SR**3**, SR**4**. The latter include respective processing parts T**5** and T**6** to process the data from the received messages and parts R**5** and R**6** for rebroadcasting a series of messages in a reliable and orderly manner in accordance with the same protocol as the parts R**3** and R**4** if one of these slave processes becomes a relay process in place of a relay process that has failed. The protocol used is that described in European patent application No. 0 650 280, for example.

FIG. **8** shows by way of example the rebroadcasting of a message m**7** sent by the source SR**3** and the rebroadcasting of a message m**8** sent by the source SR**4**. When the part R**3** of the relay process MR**3** corresponding to the source SR**3** receives the message m**7**, it recognizes that this message has come from the source SR**3**. This part R**3** rebroadcasts it in the form of a message m**7**' to all the other application processes SL**5**, SL**6**, MR**4** and to the processing part T**3** of the relay process MR**3**. The data from the message m**7**' is then processed by the processing parts T**3**, T**4**, T**5**, T**6**. In parallel with this, the message m**8** is broadcast by the source SR**4**. When the part R**4** of the relay process R**4** corresponding to the source SR**4** receives the message m**8**, it recognizes that it was sent by the source SR**4**. This part R**4** rebroadcasts it in the form of a message m**8**' to all the application processes MR**3**, SL**5**, SL**6** and to the processing part T**4** of the relay process MR**4**. The data from the message m**8**' is then processed by the processing parts T**3**, T**4**, T**5**, T**6**. The sending of m**7**' and the sending of m**8**' are coordinated by the reliable and orderly broadcast protocol so that all of the processes receive these messages in the same order, for example m**7**'–m**8**'.

The operations carried in the slave processes SL**5**, SL**6** and in the relay processes MR**3**, MR**4** are the same as those described for the first embodiment with reference to FIGS. **2** and **3**. There is just one difference: in this second embodiment operations **4** and **15**, which determine if the process concerned is the common relay process, determine if the process concerned is the relay process corresponding to the source that sent the message concerned. In a similar way to what has been described for the first example, the slave processes each include a counter, a first log register and a second log register for each source, the second being used only during an initialization phase at the time of starting up the slave process concerned.

In other embodiments of the method of the invention the number of relay processes may be greater than one without being equal to the number of sources, since the same relay process can be used for more than one source. The only condition is that all the processes used as relays include a part capable of rebroadcasting a series of messages in a reliable and orderly manner using the same protocol.

There is claimed:

1. A method of communicating messages between sources and application processes, comprising:

selecting one of said application processes as a master process having a processing task and having a relay task common to all said sources, and selecting others of said application processes as slave processes;

broadcasting messages from each of said sources to said application processes, including said master process and also all of said slave processes, said messages from said sources defining direct messages each with a respective sending source;

receiving said direct messages at said relay task of said master process and also at said slave processes;

rebroadcasting all said direct messages received by said relay task to said processing task of said master process and also to said slave processes, said rebroadcasted direct messages defining corresponding relay messages;

processing, by said processing task of said master process, data in said relay messages; and

processing, by said slave processes, data in said relay messages, and not processing data in said direct messages.

2. The method claimed in claim **1**, further comprising:

after receiving one of said direct messages at a receiving one of said slave processes, storing said direct message at said receiving slave process when said receiving slave process has not already received one of said relay messages corresponding to said received direct message;

deleting said stored direct message when said receiving slave process subsequently receives said corresponding one of said relay messages;

detecting a failure of said relay task of said master process at said receiving slave process;

determining said receiving slave process to be a new master process with a respective new relay task common to all said sources;

rebroadcasting, by said new relay task, any said stored direct message not already deleted; and

deleting, by said new relay task, any said stored direct message after said rebroadcasting.

3. The method claimed in claim **1**, further comprising:

decrementing a counter specific to a receiving one of said slave processes when receiving one of said relay messages, said counter relating to said sending source for said received relay message;

incrementing said counter relating to said sending source when said receiving slave process receives one of said direct messages from said sending source; and

concluding that said receiving slave process has not already received said relay message corresponding to a received one of said direct messages from said sending source if and only if the algebraic value of said counter relating to said sending source is positive.

4. A method of ordering a plurality of messages from a plurality of sources addressed to a plurality of application processes, each source broadcasting a series of messages in

a reliable and orderly manner and each receiving application process being capable of applying the same protocol to broadcast a series of messages in a reliable and orderly manner to all said application processes;

wherein, in order for all said receiving application processes to receive said messages in the same order, said method consists in:

selecting from said application processes a plurality of relay processes, choosing for each of said sources an application process constituting the relay process for that source, the other application processes constituting slave processes for that source, the same application process being a candidate for selection as the relay process for more than one source but each source having only one relay process;

rebroadcasting in a reliable and orderly manner messages broadcast by said source to all said application processes using said application process chosen as the relay process for a source, all said relay processes applying the same reliable and orderly broadcast protocol;

processing in said relay process for a source data from all messages that it receives directly from said source; and

processing in said slave processes only data from messages received via said relay processes, data from messages received directly from said sources not being processed.

5. The method claimed in claim **4** wherein, to remedy failure of the current relay process for a source, the method consists in, in each slave process receiving a message from a source for which it is a slave process:

storing it if said slave process has not already received the same message via said relay process for said source;

then deleting it if said slave process receives it subsequently via said relay process for said source; and

rebroadcasting and then deleting all messages stored and not yet deleted if the current relay process has failed and if the slave process in question becomes the new relay process common to all said sources.

6. The method claimed in claim **4** wherein, for determining in each process that is a slave process for a source if a message broadcast by said source has already been received by said slave process via said relay process before it is received from said source, said method consists in:

decrementing a counter specific to said slave process and to said source each time that said slave process receives a message from said source via said relay process for said source;

incrementing said counter each time that said slave process receives a message from said source directly; and

concluding that said slave process has not already received a message broadcast by a source via said relay process if and only if the algebraic value of said counter is positive.

7. System for ordering a plurality of messages from a plurality of sources addressed to a plurality of application processes capable of processing data from said messages, each source broadcasting a series of messages in a reliable and orderly manner and each receiving application process being capable of broadcasting a series of messages in a reliable and orderly manner to all said application processes, wherein, in order for all said application processes to receive said messages in the same order, said system includes:

means for choosing from said application processes a process constituting a relay process, of which there is one only for all said sources, the other application processes constituting slave processes;

means for rebroadcasting all messages broadcast by said sources from said relay process to all said application processes including said relay process;

means for processing in said relay process data from all messages that it rebroadcasts; and

means for processing in said slave processes only data from messages received via said relay process, data from messages received directly from said sources not being processed.

8. The system claimed in claim **7** wherein, to remedy failure of the current relay process, it includes in each slave process receiving a message:

means for storing said message if said slave process has not already received it via said relay process;

means for subsequently deleting it if said slave process subsequently receives it via said relay process; and

means for rebroadcasting and then deleting all messages stored and not yet deleted if the current relay process fails and if the slave process concerned becomes the new relay process common to all said sources.

9. The system claimed in claim **7** wherein, in order to determine in each slave process if said slave process has already received a message broadcast by a source via said relay process before receiving it directly from said source, said system includes:

means for decrementing a counter specific to said slave process and to said source each time that said slave process receives a message from said source via said relay process;

means for incrementing said counter each time that said slave process receives a message directly from said source; and

means for concluding that said slave process has not already received a message broadcast by a source via said relay process if and only if the algebraic value of said counter is positive.

10. System for ordering a plurality of messages from a plurality of sources addressed to a plurality of application processes, each source broadcasting a series of messages in a reliable and orderly manner and each receiving application process being capable of applying the same protocol to broadcast a series of messages in a reliable and orderly manner to all said receiving application processes, wherein, in order for all said application processes to receive said messages in the same order, said system includes:

means for choosing from said application processes a plurality of processes constituting relay processes, choosing for each source an application process constituting a relay process for said source, the other application processes constituting slave processes for said source, the same application process being a candidate for choice as the relay process for more than one source but each source having only one relay process;

means for rebroadcasting in a reliable and orderly manner messages broadcast by said source to all said application processes using said application process chosen as the relay process for a source, all said relay processes applying the same reliable and orderly broadcast protocol;

means for processing in said relay process for a source data from all messages that it receives directly from said source; and

means for processing in said slave processes only data from messages received via said relay processes, data from messages received directly from said sources not being processed.

11. The system claimed in claim **10** wherein, in order to remedy failure of the current relay process for a source, said system includes in each slave process receiving a message from a source for which it is a slave process:

means for storing a message if said slave process has not received the same message already via said relay process of said source;

means for subsequently deleting it if said slave process subsequently receives it via said relay process for said source, and

means for rebroadcasting and then deleting all messages stored and not yet deleted if the current relay process fails and if the slave process concerned becomes the new relay process for said source.

12. The system claimed in claim **10** wherein, for determining in each slave process for a source if said slave process has already received a message broadcast by said source via said relay process before receiving it directly from said source, said system includes:

means for decrementing a counter specific to said slave process and to said source each time said slave process receives a message from said source via said relay process for said source;

means for incrementing said counter each time said slave process receives a message from said source directly; and

means for concluding that said slave process has not already received a message broadcast by a source via said relay process if and only if the algebraic value of said counter is positive.

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